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# Lunar Laser Ranging Data Deposited in the National Space Science Data Center:

## Filtered Observations for 1971 July through 1971 December

and

## Unfiltered Photon Detections for 1972 January through 1972 June

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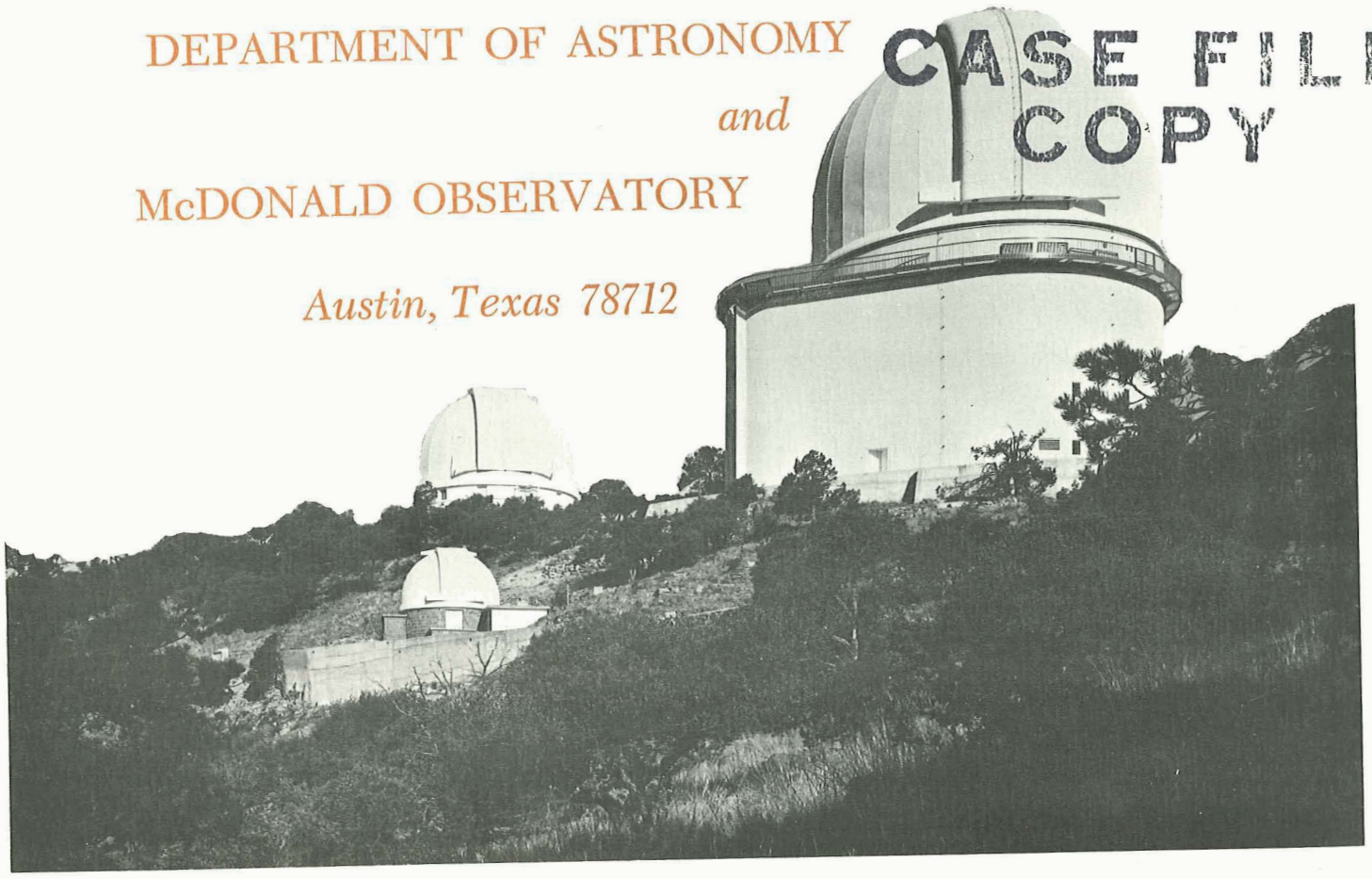

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## I. Introduction

One of the most striking new techniques in modern astrometry is that of laser ranging to a reflector fixed on a celestial object, partly because the attainable precision is so high that the data can tell us as much about Earth as about the observed object. The Apollo astronauts have now placed three widely separated reflector arrays on the Moon as a part of the Lunar Laser Ranging Experiment (LURE), the participants in which are listed in the Acknowledgements.

Although the groundwork in the experiment began much earlier, the data-taking process did not begin, of course, until 1969 July, when the Apollo 11 mission was flown. Success in recognizing returns from the reflector was not achieved until the following month. For many months there-after, various causes contributed to a very low data rate. It was not until 1970 April that regular successes became common.

From the experiment's inception, the LURE Team has recognized the obligation to make these data available in a reasonably usable form, and we have agreed upon a time-schedule that strives for a fair compromise between timely release and priority of the members of the LURE Team. This report is the documentation to be used in conjunction with the deposition in the National Space Science Data Center (NSSDC) of the filtered data obtained during laser ranging operations between the McDonald Observatory and the Apollo 11, 14, and 15 reflectors for the six months ending 1971 December 31 and the unfiltered photon detections for the succeeding six months. These two blocks

will be discussed in more detail in subsequent sections of this memorandum.

## II. Observatory and Reflectors

The laser ranging equipment is mounted on the 272 cm reflector at the McDonald Observatory, Fort Davis, Texas. The physical installation has been so thoroughly described in the literature (e.g. Silverberg and Currie 1972) that it seems unnecessary to dwell on it here. The nominal coordinates presently recommended for this instrument, based on high-order land survey ties to the SAO Organ Pass Tracking Station, are

| | |
|---|---|
| geocentric radius | $\rho$=6374.665 km |
| east longitude | $\lambda$=+255.97779 degrees |
| geocentric latitude | $\varphi'$=+30.50320 degrees |

These refer to the intersection of the polar and transverse axes of the telescope. The center of the primary mirror, as the telescope tracks across the sky, describes a circle of radius 305 cm whose plane is normal to the polar axis.

The present data refer to the reflectors at Tranquility Base, Fra Mauro and Hadley, whose nominal coordinates are

| | Tranquility | Fra Mauro | Hadley |
|---|---|---|---|
| selenocentric radius | $\rho$=1735.730 km | 1736.680 | 1735.64 |
| east longitude | $\lambda$=+23.485 degrees | -17.4628 | +26.094 |
| latitude | $\beta$=+0.642 degrees | - 3.6680 | + 3.673 |

based on data supplied by NASA/MSC during tracking operations during the Apollo missions.

## III. Filtered Data

The photon detections have been submitted to a data filtering procedure developed at the University of Texas. This process is based on the assumption of the linearity of Ø-C residuals over a relatively short time interval and relies on Poisson statistics for establishing a level of confidence in a collection identified by the filter. Application of the process resulted in the identification of the observations during the subject interval.

The potential user should be aware that the laser cannot be relied upon to produce a simple pulse shape. There sometimes is a complex and/or biased structure within the pluse. Therefore, residuals derived from signal photons are not necessarily expected to show a Gaussian distribution. The uncertainties assigned are based on the sum of the pulse half-width and the measured uncertainty in calibrating the electronic system. Beginning with the April-May, 1972 lunation a letter code appears in column 32 (formerly unused) of the "Ø" card image which provides an estimate for the accuracy of the electronic calibration correction. The following code is used:

A - better than ±200 picoseconds
B - ±200 to ±400 picoseconds
C - ±400 to ±600 picoseconds
D - ±600 to ±1000 picoseconds
E - ±1.0 to ±1.5 nanoseconds
F - ±1.5 to ±2.0 nanoseconds
G - ±2.0 to ±4.0 nanoseconds
H - worse than ±4.0 nanoseconds

The calibrations were performed by E. C. Silverberg. Otherwise, the data format is as defined by Mulholland (1971).

## IV. Unfiltered Photon Detections

It is most important that the potential user observe the designation "unfiltered". By this, we mean that the real data are heavily interspersed with noise photons from any of the various sources of stray light. Any attempt to use these data in a simple Gaussian application would probably result in a solution closely adhering to the prediction ephemeris used to control the detector range gating. Some filtering process needs to be applied to these data before effective use can be made of them. Such filtering is now underway at the University of Texas at Austin, and all filtered data will also be deposited with NSSDC, but the unfiltered data may be of direct utility or interest to those potential users who may wish to replace our filter criteria with their own. These data also conform to the data format standard referenced above, except that the clock epoch error carries the opposite sign, as is the case with all previous NSSDC depositions.

## V. Data Description

The data are contained on two files of a binary magnetic tape written in card image format, using a CDC 6600 computer. It is written with odd parity at 800 bpi. Two types of cards are present, distinguished by an alphabet character in column 1: The letter Z designates a "run" card, giving environmental and operational parameters for a series of shots. Except for clock epoch error, these will not customarily be required for application of the range data, but serve to provide information on the observing conditions and the state of the equipment. Most users will find them helpful

only as separators between observing sessions. The letter P in column 1 represents a "shot" card, containing the result of a single laser firing.

A word of warning is in order to the unwary users. Some of the specified data items may not be available. In the card images, a blank field is a "no information" indicator. Actual null values will be represented by zero punches.

## VI. Acknowledgements

The data described herein were generated at the McDonald Observatory through the collective efforts of the LURE Team and numerous supporting personnel at their several institutions. The team is composed of C. O. Alley and D. G. Currie (U. of Md.), P. L. Bender and J. E. Faller (JILA), R. H. Dicke (Princeton U.), D. H. Eckhardt (AFCRL), W. M. Kaula (UCLA), J. D. Mulholland and E. C. Silverberg (McDonald Obs. and U. of Tx), H. H. Plotkin (NASA/GSFC), J. G. Williams (JPL). Executive Secretary is A. T. Strickland (NASA HQTRS). Preliminary processing of data prior to 27 August 1971 was done at the University of Maryland and was provided by D. G. Currie to the authors for this purpose. Subsequent to this date all processing of data was performed at the University of Texas at Austin. This report and the data tapes described herein were prepared under NASA Grant NGR 44-012-219.

## VII. References

Mulholland, J. D. 1971, "Proposed Standards for Distribution and Documentation of Lunar Laser Ranging Data" COSPAR Bulletin, No. 61 (March).

Silverberg, E. C., and Currie, D. G. 1972, "A Description of the Lunar Ranging Station at McDonald Observatory" Space Research XII (Akademie-Verlag, Berlin).